A Knowledge-Based Creation of Mathematical Programming for GIS Problem Solving

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***Abstract*—Nowadays the biggest challenge to GIS is the model design of theme analyzing. Many GIS applications need more functions in analysis and decision-making than in data organization or visualization. While confronted with an application like planning a new metro line in a city, the typical GIS cannot accomplish it by itself, unless some human experts or artificial intelligence technology are involved. Numbers of GIS applications essentially are models of theme analyzing, and they are also examples of problem solving in AI. Therefore many theories and technologies from AI can be embedded in GIS to strengthen its ability of automatic analysis. Fortunately mathematical programming is a kind of powerful tool to settle problems with a demand of optimization under some constraint conditions. Many GIS applications happen to be this type, and some mathematical models can usually approximate them accurately. Two new questions aroused. The first is what objective function and constraint conditions that constitute a mathematical programming should be, and the second is how to acquire those mathematical expressions. Due to the establishment of a mathematical programming is highly knowledge-based, so an AI subsystem is designed to autonomously create a mathematical programming. This problem has a typical characteristic of multiple domains crossing from perspective of Knowledge Engineering, so some novel knowledge-processing methods, like knowledge dependence, knowledge transition and knowledge reference, are studied. And a knowledge system represented by frames and a reference-based knowledge-using method are presented here.**

Keywords- Artificial intelligence; GIS; Automatic programming

I. INTRODUCTION

One type of important applications in Geographical Information System (GIS) is to solve distribution or optimization problem rationally. Such as how to allot planting area of different crops on a limited cultivated land so as to make good use of cultivated land and get quite good economic benefit. Or how should a retail company decide its stores' locations and their scales in a city such that it can maximize the ratio of product to investment. Or how should a tourist reasonably arrange several days' traveling plan according to the characteristics of a visiting place, weather condition, and his/her affordability. Or how should an investor of transportation facility build a metro in a city so as to maximize its value, etc. They are all typical problems in problem solving of Artificial Intelligence (AI). They have two common characters. One is involving a great deal of geographic or spatial information, the other is the usage of knowledge in some professional domains is required.

An enhanced GIS, such as combining GIS with Expert System, Decision Support System or other methods in AI, is usually called Intelligent GIS. This type of hybrid information system is widely used in the areas of agriculture, forestry, ecosystem, traffic, transportation, environmental protection, public health, and so on.

An intelligent GIS as a monitoring and forecasting system to model the effects of fire, grazing, thinning and protection on species composition, canopy coverage and resource values in the oak-woodland in California was presented in [1]. In the paper, a combination of GIS and expert system methodologies was used in a state-transition paradigm. A hybrid Expert-GIS model that was composed of an expert system to capture the expertise of an entire incident management team and a GIS as the user interface was discussed in [2]. The knowledge-based system was Multi-modular and each module served as one decision module aimed at providing a specific ability to the Expert-GIS system. In paper [3], a microcomputer-based decision support system, namely Spatial Intelligent Multi-criteria Environmental Sensitivity Evaluation Planning Tool was applied to evaluate the multi-criteria Environmental Sensitivity of the Geelong road network, in Victoria, Australia. It used Fuzzy Set Theory, multi-criteria decision-making techniques. A tool that has been developed to support Geographic Knowledge Discovery in the field of environmental health was presented in paper [4]. This tool enhances GIS software with Spatial On-Line Analytical Processing capabilities to better support decision-making for health users. The system described in a paper [5] is a spatial decision support system in GIS involving a knowledge-based approach. Its aim was to compute a map of potentiality for problem solution with production rules about environmental knowledge. In paper [6], by linking a rule-based qualitative simulation model with a geographic information system, a brief review of the state-and-transition

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methodology was presented and then a computer-based implementation of a spatially explicit state-and-transition model was described.

However, GIS requires more sophisticated reasoning mechanisms for processing dynamic information and knowledge of the real world. Thus, to what extend the knowledge-based intelligent methods are embedded in GIS is important. So the solution made by human or by software is a big difference to denote whether GIS-based software is a management tool or an intelligent partner.

From the perspective of mathematics, foregoing GIS applications, such as task scheduling, resource allocating, cost minimizing, benefit maximizing, etc, are optimization of variables under some constraints. A mathematical programming can solve all of them. As mathematical programming is a pure calculation problem and computer is right adept in mathematical calculation, so once a proper set of variables, equations or inequations can be produced by some mechanism to instantiate a GIS application, the remaining procedures are easy to handle. But a difficulty is how an enhanced GIS can obtain a set of definitions in a form of mathematical programming by itself. For instance how does an enhanced GIS get to know which variables should be abstracted and formalized, or which variable it should optimize and what is the standard of optimization, or what mathematical relationships several variables should satisfy? The aim of this paper is to find a practicable method of producing a mathematical programming for problem solving in GIS application. What this paper focuses on is to introduce how to obtain the optimization object and constrains for the mathematical programming by using knowledge.

This paper is divided into 5 sections. The first part is introduction of AI-based GIS applications and why mathematical programming can solve problems. The 2nd section presents a conceptual model of problem solving in GIS. The 3rd section explains the whole process of creating a mathematical programming for GIS problem solving, and some new methods of knowledge representing, referring and reasoning concerned are presented here. The 4th section is an example of using knowledge-based programming method to plan a new metro line. The last section is conclusion.

II. AN ENHANCED GIS MODEL

Facing complex applications, if GIS is merely a tool for storing data, fusing information and visualization, it is only a secondary platform to those problem-solving tasks, because the users of GIS commit the most difficult and also most important procedure in tasks. A real challenge comes from the following idea: let computer perform the problem-solving task as much as possible, i.e. transfer a part of work previously done by domain experts to a function-enhanced GIS. So we need following components.

The first part is domain knowledge base and its maintenance component. In form the knowledge base includes two types of knowledge, one is fact and the other is rule. Domain knowledge are those specialized or professional knowledge that only experts might possess and know how to use.

The second part is meta-knowledge operation. Meta-knowledge is the knowledge of how to use domain knowledge. For instance the question is how to select locations to build stations of a new metro line. Then in order to answer this question, knowledge of knowing to select one target to optimize is obviously more essential than knowing what is that target or using some knowledge to optimize it. The quantity of meta-knowledge is much less than that of domain knowledge, but the former is more dominant, because they control the whole proceeding of problem solving. We divide this part into a problem analysis module and a formalization module. The former is to judge the contents of possible solution of the question and the later is to form a data structure for the solution of the question. In theory the research on meta-knowledge usage is still an open problem, whereas considering that we had confined our questions all came out of constructing metro line, so we can in advance evaluate the categories of questions.

The third part is the operation of problem solving. Why we choose mathematical programming is owing to its great advantage of non-problem pertinence. The processes of problem solving are formalized into a set of constraint conditions and an objective function, to which we can use linear programming method to obtain relative optimal results. That is to say programming technology is suitable to an intelligence-required application that might be confronted with many variances in problems' appearances. Here problem-solving part includes two modules: one is reasoning module for mathematical programming acquisition and the other is calculating module. The essential of programming method is the definition and construction of the constraints and the objective function, for all of them are highly knowledge-based.

III. HOW TO CREATE A MATHEMATICAL PROGRAMMING BY KNOWLEDGE APPLYING

Mathematical Programming is a powerful tool to solve above problems. A mathematical programming always consists of an objective function and some constraint conditions. Once obtaining such set of mathematical formulas, it's not difficult to solve it. The actual issue is that: how to get a mathematical form that is corresponding with a special task by the aid of knowledge. For instance, the cost of building the metro must include the cost of digging a tunnel. Why? It seems that it's a common sense, but does the automatic programming program understand that digging tunnel is necessary while building a metro?

Designing a metro line is a typical problem-solving task in GIS application, because use of knowledge is absolutely necessary for solution seeking. The programming method is compact in form and independent to any special application, and the calculation of mathematical programming can be done mechanically. The programming here can be seen as a process of establishing a mathematical model, usually including one objective function and several constraint conditions. However how to formalize an application and obtain an appropriate mathematical model from it is difficult, owing to the uncertainty of the form and the quantity of knowledge that might be involved in formulas establishment. In this perspective, the problem solving in complicated GIS application should apply methods of Artificial Intelligence that is skillful in dealing with knowledge-involved problem through its sophisticated knowledge representing and reasoning mechanisms. Thus we regard the problem solving in complicated GIS application as a knowledge-based and geographically referenced knowledge processing.

In details, if a city needs a new metro line, then we will decide where and how many stations should be built and how to connect two neighboring stations. During decision making planners should in advance consider several indispensable factors, such as current traffic demand, distribution of citizens, the topographical and geological constraints, the functions of candidate locations, environmental and ecological protection, etc. All these reasonable considerations will restrict the candidate metro lines in a comparative limited range. It is obvious that all concerned knowledge should be materialized by a set of programming formulas, whereas we can not take it for granted that a computer can get this considerate programming like an expert. Fig.1 explains an idea of automatically creating a mathematical programming for problem solving in a domain of public traffic.

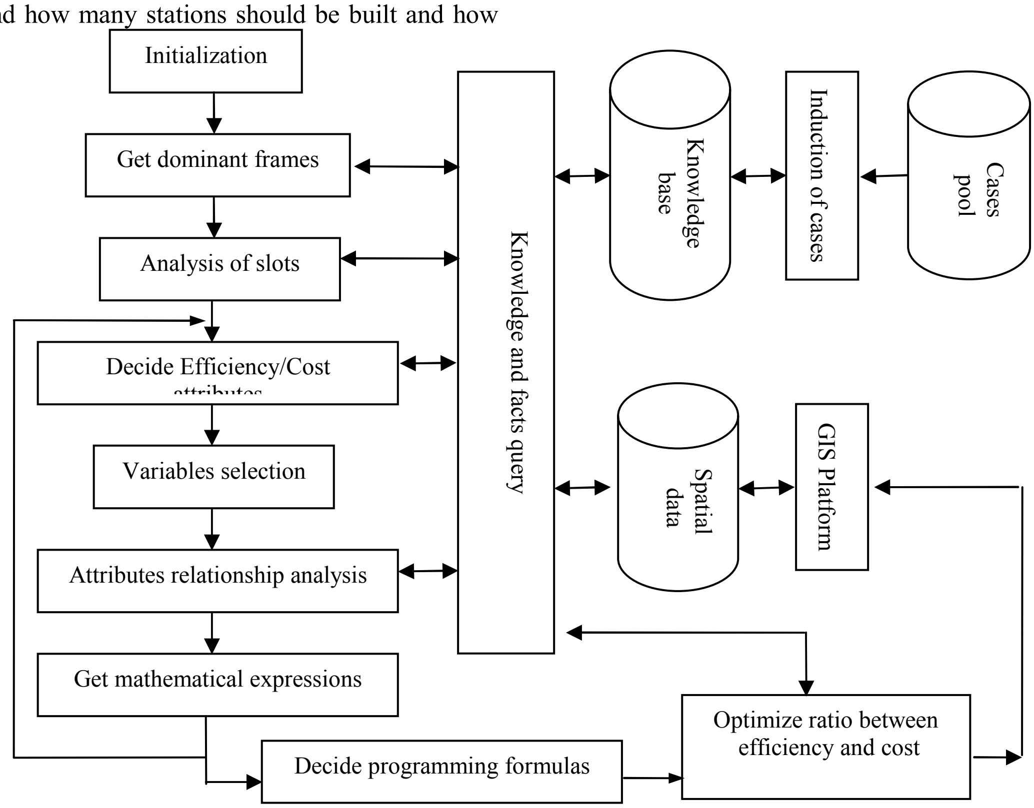

Figure 1. Knowledge-based mathematical programming creating

GIS problem resolving applications are usually space planning or predicting. The knowledge involved is usually about limited specific domains such as geography, geology, environment, natural resource, population, city layout, etc. So, specific GIS background can satisfy the premise of effectively formalizing knowledge. This system adopts a knowledge representing method that combining frames with variable table, function table and mathematical operation table.

Auto-creation procedure of mathematical programming based on knowledge is a knowledge-driven procedure, whose basic operations are the following: (a) User comes out with a form of activating knowledge base. Take the plan of metro line at present for instance, which can be depicted by a form of "Predicate (object)": Produce (Mathematical Programming (Construction (Metro line))). It is a compound concept composed of several more basic concepts, and it is also a compound script. (b) Decomposition of problem. By use of knowledge items that had been activated, the initial auto-creation problem can be divided into several sub-goals, and sub-goals can be divided further into sub-sub-goals according to whether solutions for them are obtained. This kind of decomposition will proceed until solutions of all sub-goals had been sought. (c) Search in knowledge base. The process of solving sub-goals in different levels is translated into searches in a knowledge base of frames and scripts according to searching conditions. (d) Knowledge instantiation operation. We instantiate an active frame or script that represents a generic concept or procedure by. (e) Consistency checking of solution. Before ascertaining a solution in some level, check whether there are evidences contradicting with this solution in active knowledge items. It is consistent if there are not contradictions.

IV. EXPERIMENTS AND RESULT ANALYSIS

Fig.2 is a traffic sketch of Shanghai, which distributes roads, railway lines, rivers, residential areas and public facilities, etc. In order to consummate railway traffic networks, the municipal government wants to build a new railway to connect railways running north south and railways running east west, and two junctures are circled in Fig.2. The blue line in the figure is the circuit of constructing actually, while the red one is an experiment result generated by Mathematical Programming. As we can see that those two lines overlapped very well.

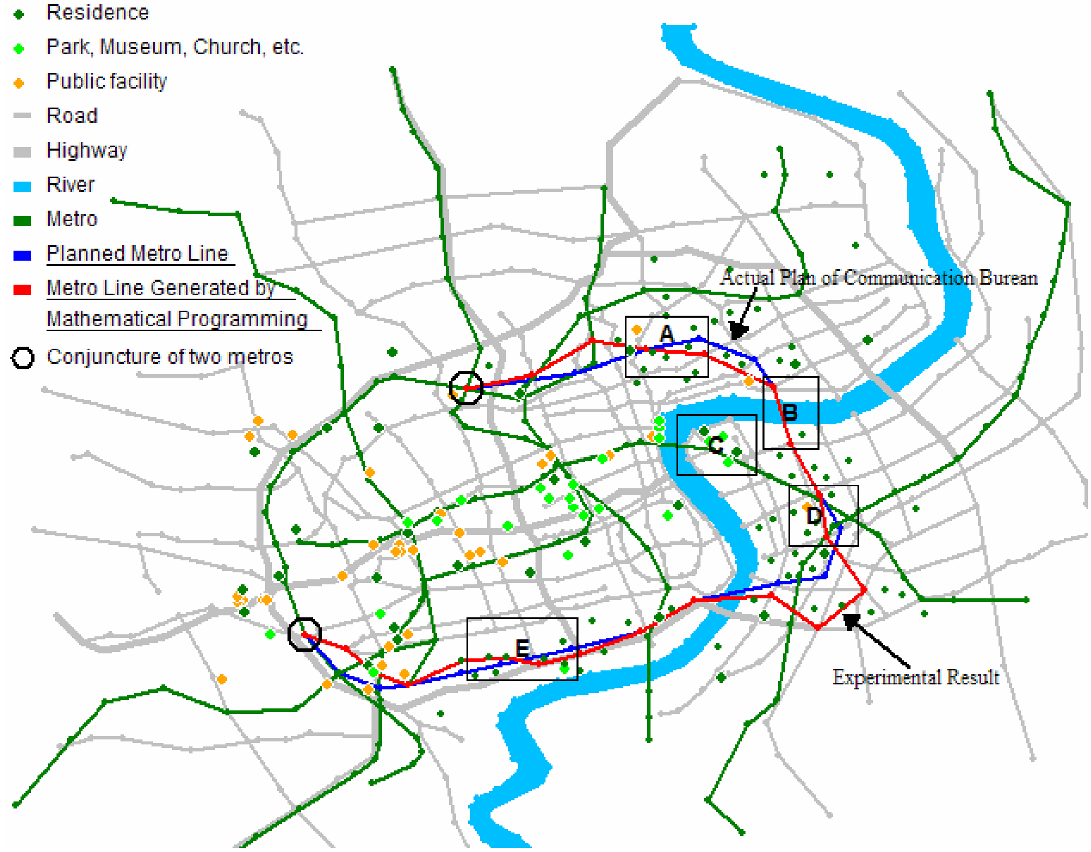

Figure 2. Metro and light railway sketch plan of Shanghai

V. CONCLUSION

Artificial intelligence technology can be used comprehensively in GIS applications. By taking advantage of accurate position-related information processing based on the GIS platform and sophisticated knowledge representation and reasoning methods in AI, we are capable of solving more complicated problem by the enhanced intelligent GIS than common GIS applications. Programming method is adept at calculating precise mathematical formulation, so we can build a mathematical model with knowledge integrated into the GIS database and complete problem solving through mathematical programming method. Other than mathematical programming, it is conceivable that many techniques and methods in AI can be integrated into GIS to an extent of more adaptability and greater depth of embedding to achieve better performance, which is worthy of study in the future work.

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